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Densities of beneficial arthropods within pear and apple orchards affected by distance from adjacent native habitat and association of natural enemies with extra-orchard host plants

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Abstract

Beneficial arthropods were sampled using beat trays in 10 pear and 8 apple orchards in Washington and Oregon, USA. One border of each orchard was adjacent to non-agricultural land (extra-orchard habitat). Beneficial arthropods were also sampled on 45 species of plants in extra-orchard habitats adjacent to study orchards. Orchard samples were taken monthly at 2 or 3 distances (depending upon size of the orchard) from the edge adjacent to extra-orchard habitat. An overall mean of 33.8 beneficial arthropods was taken per 26-tray sample (43.8% spiders; 37.8% predaceous insects; and 18.5% parasitoids). In May, July, and August, densities of beneficial arthropods declined significantly as distance from extra-orchard habitat increased. The decline was most evident in spiders and parasitoids; no trend was noted for predaceous insects. Most of the decline occurred between 0–60 and 60–120 m into the orchard, with no significant decline between 60–120 and 120+ m. These results are consistent with the idea that some taxa of beneficial arthropods moved into orchards from extra-orchard habitat. The most common predaceous insects in orchards were Miridae (32.3% of beneficial insects), Coccinellidae (11.1%), Chrysopidae (6.9%), and Hemerobiidae (5.7%). Important parasitoids were *Trechnites insidiosus* (7.6% of beneficial insects) and *Pnigalio flavipes* (2.3%). The families Linyphiidae, Salticidae, Oxyopidae, Philodromidae, Theridiidae, and Clubionidae together comprised 87.3% of total spiders. Twenty-two taxa of spiders and 22 taxa of beneficial insects collected in orchards were also collected on plant species outside of the orchards. The predatory insects *Orius tristicolor*, *Deraeocoris brevis*, and *Nabis alternatus* and the spiders *Misumenops lepidus* and *Oxyopes scalaris* were collected on the largest number of extra-orchard plant species. Common parasitoids of orchard pests were never collected from extra-orchard host plants.
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1. Introduction

As pear and apple growers in the Pacific Northwestern region of the United States shift to more selective control technologies for major arthropod pests, there is often a noticeable increase in densities of natural enemies in the orchards (Epstein et al., 2000; Knight et al., 1997; Miliczky et al., 2000). In some instances, increased natural enemy density has been shown to result in higher levels of biological control (Knight et al., 1997). Unfortunately, response by natural enemies to lower insecticide use may be highly variable among orchards (Gut and Brunner, 1998), and this variability is poorly understood. Moreover, variability in response has led to reluctance by many growers to rely largely or exclusively on biological control as a means of controlling pests. Improved understanding of factors that affect orchard-to-orchard differences in densities of natural enemies would be useful.

One factor likely to affect densities of natural enemies in orchards is immigration. Among pear and apple

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growers in the northwestern United States a perception exists that the type of habitat adjacent to an orchard affects the level of biological control potentially realized in the orchard. That is, orchards adjacent to areas of non-agricultural land, specifically land of a relatively undisturbed character with a high proportion of native plant species, may experience higher levels of biological control than orchards surrounded by other orchards, other cropland, or land otherwise highly disturbed. This type of land is referred to here as extra-orchard habitat and in this study included areas of sagebrush steppe, riparian tracts along watercourses, and woodland habitat. The presumption is that extra-orchard habitat acts as a source of natural enemies that may move into the orchard, as suggested elsewhere for certain predatory bugs that often occur in pear orchards in the Pacific Northwest (Horton and Lewis, 2000). The idea that extra-orchard habitats, or comparable habitats adjacent to other crops, act as sources of natural enemies for agricultural systems has been expressed or tested directly for a number of crop ecosystems (Duelli et al., 1990; Ekbom et al., 2000; Sotherton, 1985; Thomas et al., 1992). It is assumed that some natural enemies rely on extra-crop habitats for resources not provided within the crop such as alternative prey or hosts, sites for mating, and refugia for molting and overwintering (Letourneau, 1998).

If natural enemies are indeed dispersing into orchards from extra-orchard habitats, we might expect densities of these arthropods to be highest in the section of the orchard adjacent to extra-orchard habitat, and that densities would decline as distance from the habitat increased. We tested this hypothesis in 18 reduced-pesticide pear and apple orchards located in central Washington and north-central Oregon by sampling trees along transects from the orchard perimeters into the orchard interiors. We looked for seasonal trends in densities of natural enemies along these transects that might lead to a better understanding of the phenology and extent of dispersal for key predator species. Concurrently, we sampled plant species in the extra-orchard habitats to determine if natural enemies of orchard pests also occurred on plants outside of the orchards.

2. Materials and methods

2.1. Description of the study sites

Eighteen orchards in Washington and northern Oregon were chosen for study: 10 pear and 8 apple. All were under reduced insecticide management programs and relied on mating disruption, rather than application of broad-spectrum insecticides, as the primary means of controlling codling moth, *Cydia pomonella* L. Three apple and three pear orchards were state-certified organic. One edge of each orchard was adjacent to a tract of extra-orchard habitat whose principal vegetation consisted of native plant species. The other three sides abutted other orchard habitat, other crops (grapes, for example), or disturbed land with few or no native plant species (weedy, non-producing agricultural land, for example). In no case was a second side of an orchard also adjacent to extra-orchard habitat as defined in the introduction. Ten orchards were located in Yakima County, Washington; three were in Chelan County, Washington; one was in each of Walla Walla, Grant, and Kittitas Counties, Washington; and two were in Hood River County, Oregon. Cardinal direction of the extra-orchard habitat relative to the orchard, varied from orchard to orchard.

Extra-orchard habitats adjacent to study orchards could be broadly categorized into 1 of 3 types. Two pear orchards were adjacent to riparian habitat along rivers where the vegetation included trees and shrubs such as *Populus trichocarpa* T. & G., *Salix* spp., *Symphoricarpos albus* (L.) Blake, *Prunus virginiana* L., and *Rosa woodsii* Lindl. Four pear blocks bordered mixed hardwood/coniferous woodland where trees included *Pinus ponderosa* Dougl., *Pseudotsuga menziesii* (Mirbel) Franco, *Acer macrophyllum* Pursh, and *Quercus garryana* Dougl. Understory shrubs and herbs at the wooded sites were quite diverse and all four had been logged to varying degrees. Sagebrush steppe was the habitat most frequently found adjacent to our study orchards (four pear, eight apple). Shrubs such as *Artemisia tridentata* Nutt., *Purshia tridentata* (Pursh), and *Chrysothamnus* spp. occurred at most sites but the number of associated species varied widely. During peak flowering, late April to late May, the number of species in flower varied from fewer than 15 to as many as 30.

2.2. Sampling

To determine how distance from extra-orchard habitat affected densities of natural enemies within the orchard, we divided each orchard into two (five small orchards) or three (13 large orchards) sections, with each section occurring at a successively greater distance from the extra-orchard habitat. The section of the orchard nearest the extra-orchard habitat extended 60 m from the orchard/extra-orchard habitat margin into the interior of the orchard along a line perpendicular to the orchard/extra-orchard habitat margin. The second section extended from 60 to 120 m into the orchard along the same line. In the 13 large orchards a third area was defined that included the section of the orchard more than 120 m from the extra-orchard habitat.

Orchards were sampled monthly from May to October by taking 26 beat trays (one tray per tree) in each section of an orchard. Two people (each sampling 13 trees per section) did all within orchard sampling. Beat tray samples were also collected from plants in the extra-orchard habitat at all orchards except one pear block where the habitat was difficult to access. Generally, 10 or 20 beat trays (one tray per plant) were taken from a given plant species on a sample date. Plant species were chosen for sampling based on relative abundance, accessibility, and state of bloom. Common species were sampled each month while less common species were sampled once or twice during the season. Arthropods dislodged by beating fell onto a canvas beat tray (72.5 cm × 69.5 cm; Area ~0.5 m^2) and were collected with an aspirator. We attempted to collect all spiders, insect predators, and parasitoids that fell onto the tray and also a sample of pest or herbivorous taxa present. Most specimens were preserved immediately in 70% isopropyl alcohol for later processing and identification. Immatures of some spiders and predatory insects were reared to the adult stage for positive identification.

2.3. Statistical analyses

We used repeated measures analysis of variance to determine if counts of natural enemies changed with increasing distance into the orchard; distance was the repeated factor. Two analyses were done: large orchards only ($n = 13$), which allowed us to include all three distances (0–60, 60–120, and >120 m) in the analysis; and, all orchards ($n = 18$) for which we used only the first two distance classes (due to the smaller size of the five additional orchards). Two profile contrasts were extracted for each repeated measures analysis for the large orchards, to allow us to compare adjacent distance classes (0–60 vs 60–120 m and 60–120 vs >120 m). These contrasts allowed us to determine if distance effects were concentrated primarily immediately adjacent to the native habitat (i.e., first contrast significant, second contrast non-significant) or if the distance effects occurred over the entire sampled area (i.e., both contrasts significant). Separate analyses were done for each sample month and a final analysis used seasonal means.

3. Results

3.1. Beneficial arthropods within the orchards

Total beneficial arthropods averaged 33.8 per 26 tray sample (data averaged over the 18 orchards, the six sample months, and the first two distance classes) of which 43.8% (14.8 per sample) were spiders, 37.8% (12.8 per sample) were predaceous insects, and 18.5% (6.3 per sample) were parasitoids.

Miridae (Hemiptera) were the most abundant predaceous insects collected during the study. *Campylomma verbasci* (Meyer) and *Deraeocoris brevis* (Uhler) comprised 16.9 and 15.4% of total beneficial insects, respectively. Coccinellidae (11.1% of total beneficial insects), Chrysopidae (6.9%) and Hemerobiidae (5.7%) were less abundant. All four families are important components of biological control systems in orchards. The mite predator *Stethorus picipes* Casey accounted for 502 of 597 total Coccinellids, 334 of which were taken in one orchard during September and October. Adult Hemerobiidae were most abundant late in the season; 66% (140 of 213 total specimens) were taken in October. Adults of at least five species of *Hemerobius* were collected in orchards (no attempt made to identify larvae). These were, in order of abundance: *Hemerobius ovalis* Carpenter, *Hemerobius neadelphus* Gurney, *Hemerobius pacificus* Banks, *Hemerobius bistrigatus* Currie and *Hemerobius stigma* Stephens.

Spiders occurred in all orchards and hunting spiders were generally more numerous than web-spinners. The most common families (with representative genera in parentheses) and their percent composition in the total spider fauna were: Linyphiidae (*Meioneta*, *Erigone*)—29.2%; Salticidae (*Pelegrina*, *Phidippus*)—21.1%; Oxyopidae (*Oxyopes*)—14.5%; Philodromidae (*Philodromus*)—11.2%; Theridiidae (*Theridion*)—6.8%; Clubionidae (*Cheiracanthium*)—4.5%; Thomisidae (*Xysticus*, *Misumenops*)—4.1%; and Tetragnathidae (*Tetragnatha*)—2.6%. The number of spiders exceeded the total number of beneficial insects (predators and parasitoids) in 51.1% of the samples.

Two parasitoids important in biological control were abundant in some orchards. *Pnigalio flavipes* (Ashmead) (Hymenoptera: Eulophidae), a parasitoid of the western tentiform leafminer, *Phyllonorycter elmaella* Doganlar & Mutuura (Lepidoptera: Gracillariidae), comprised 2.3% of total beneficial insects. It was found in 12 of the 18 orchards. *Trechnites insidiosus* (Crawford) (Hymenoptera: Encyrtidae), a parasitoid of the pear psylla, *Cacopsylla pyricola* (Foerster) (Homoptera: Psyllidae), comprised 7.6% of total beneficial insects and was found in 8 of 10 pear orchards. Parasitoid wasps in 15 other families were found in the orchards: Ichneumonidae, Braconidae, Scelionidae, Platygastridae, Proctotrupidae, Diapriidae, Ceraphronidae, Megaspilidae, Figitidae, Eucoilidae, Charipidae, Mymaridae, Aphelinidae, Bethylidae, and Dryinidae. Species identities and hosts for few of these are known.

Substantial orchard-to-orchard and month-to-month variation in counts of natural enemies was noted in both pear and apple orchards (Fig. 1). In addition, mean natural enemy densities differed between apples and pears in several monthly samples (Fig. 1). This was most notable for counts of all beneficial arthropods and for spiders, less so for predaceous insects and parasitoids. Mean spider densities, for example, differed markedly between apples and pears in all months, with spider densities in apples exceeding those in pears from May to September. On the other hand, parasitoid densities in

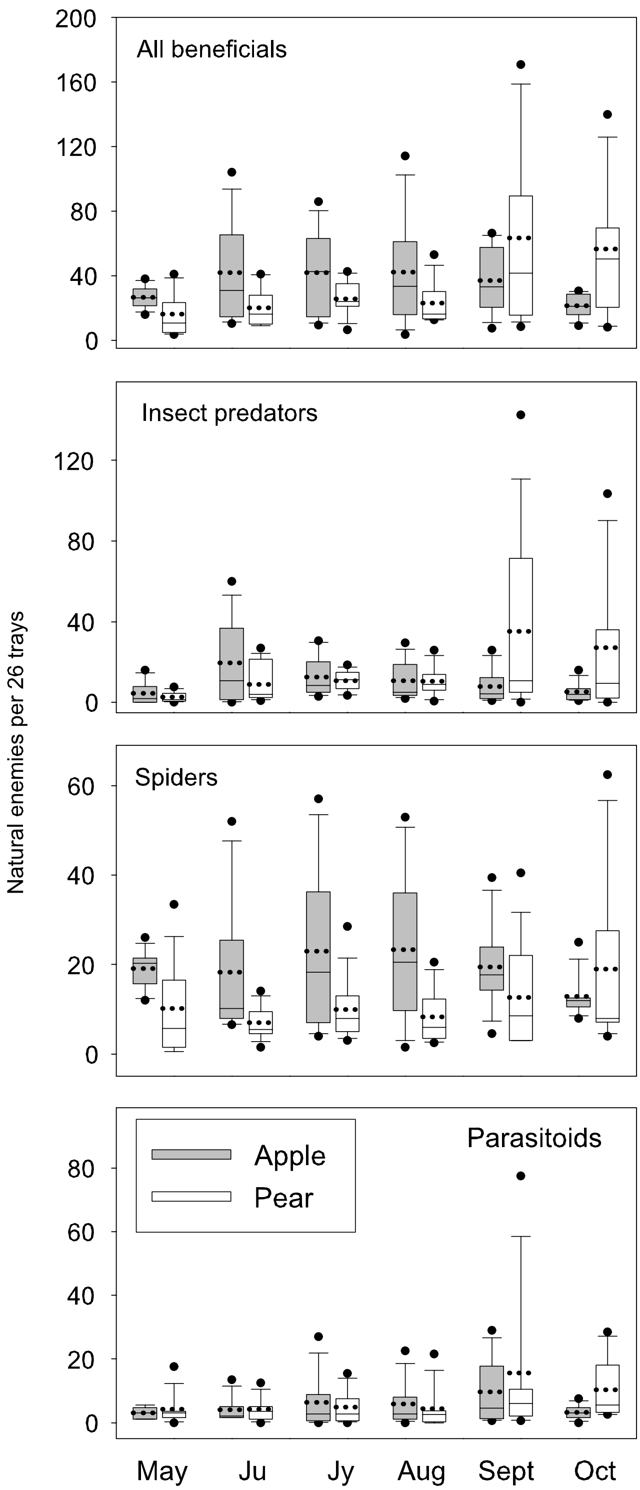

Fig. 1. Box plots showing counts of natural enemies per 26 trays in apple and pear orchards. Box boundaries depict 25th and 75th percentiles; median shown by solid horizontal line; mean shown by dotted horizontal line; 10th and 90th percentiles shown by error bars; range shown by filled circles. $N = 18$ orchards. Data averaged over first two sampling distances in each orchard.

both crops were similar in four of the six months and insect predator densities were similar in three of the six months.

Mean densities of total beneficial arthropods in apples were high from June to September but fell off markedly in October (Fig. 1). Recently hatched spiderlings contributed greatly to the high densities. Spiderlings actually began to appear in considerable numbers in May and continued to appear through September. Common species included *Meioneta fillmorana* (Chamberlin), *Pelegrina aeneola* (Curtis), *Xysticus cunctator* Thorell, *Oxyopes scalaris* Hentz, *Cheiracanthium mildei* L. Koch, and *Philodromus cespitum* (Walckenaer).

Mean density of total beneficial arthropods in pear orchards peaked in September and declined slightly in October, in contrast to the trend observed in apples (Fig. 1). Beneficial arthropods in each of the three groups contributed to this late season peak. The predatory insects *D. brevis*, *C. verbasci*, and *S. picipes* reached their highest numbers of the season, although numbers varied from orchard to orchard. Abundance of the psyllid parasitoid *T. insidiosus* also peaked in September and October, although its numbers were not high in all orchards. Finally, spider densities peaked in the pears during September and October.

Distance effects were summarized for large orchards only (three distances; $n = 13$ orchards; Figs. 2–5, filled circles) and for all orchards (two distances; $n = 18$

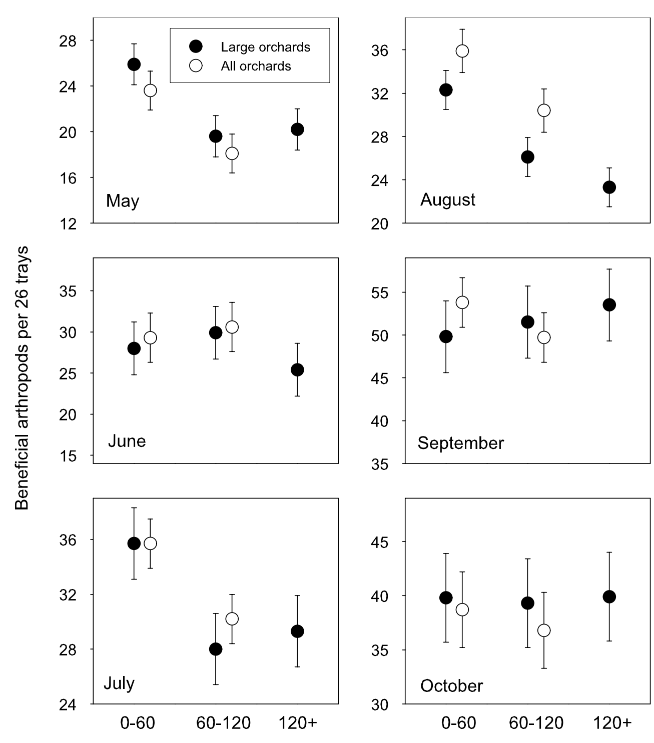

Fig. 2. Mean (±SEM) number of beneficial arthropods per 26 trays as a function of distance into the orchard. Filled symbols: large orchards only ($N = 13$); open symbols: all orchards ($N = 18$).

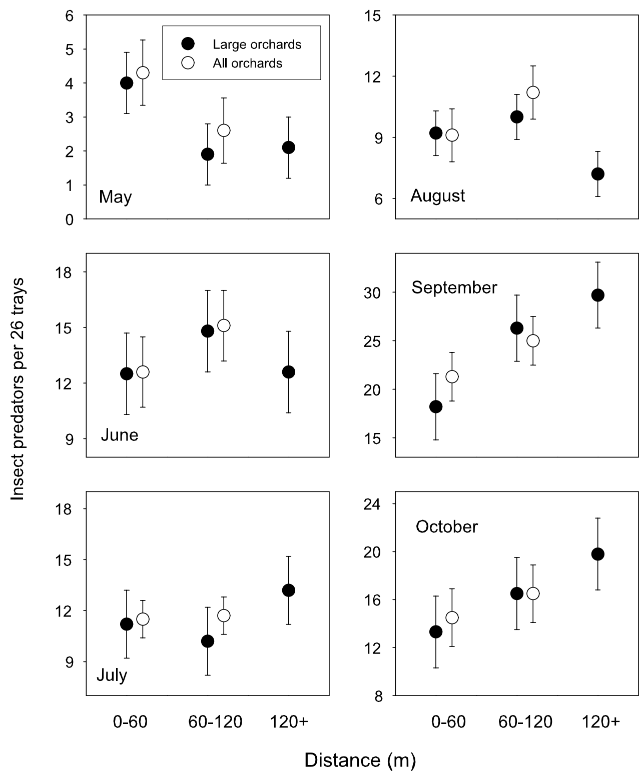

Fig. 3. Mean (±SEM) number of insect predators per 26 trays as a function of distance into the orchard. Filled symbols: large orchards only ($N = 13$); open symbols: all orchards ($N = 18$).

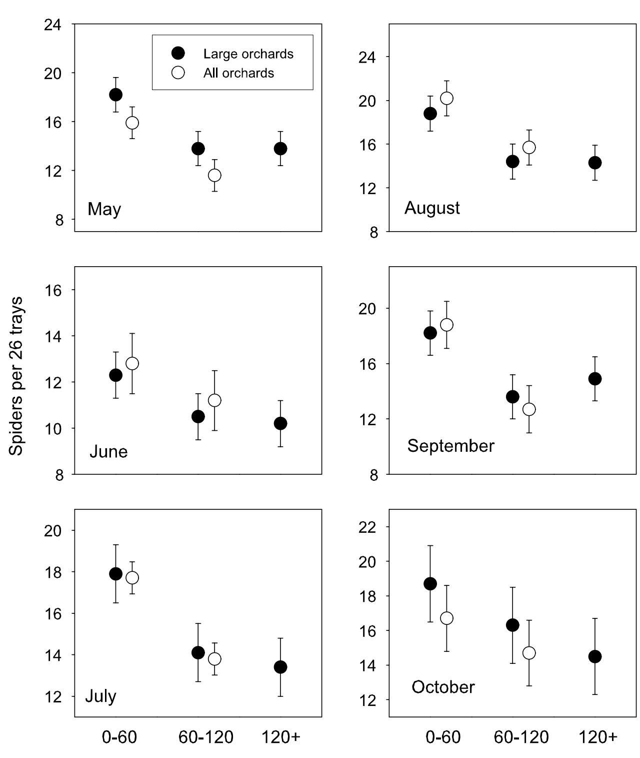

Fig. 4. Mean (± SEM) number of spiders per 26 trays as a function of distance into the orchard. Filled symbols: large orchards only ($N = 13$); open symbols: all orchards ($N = 18$).

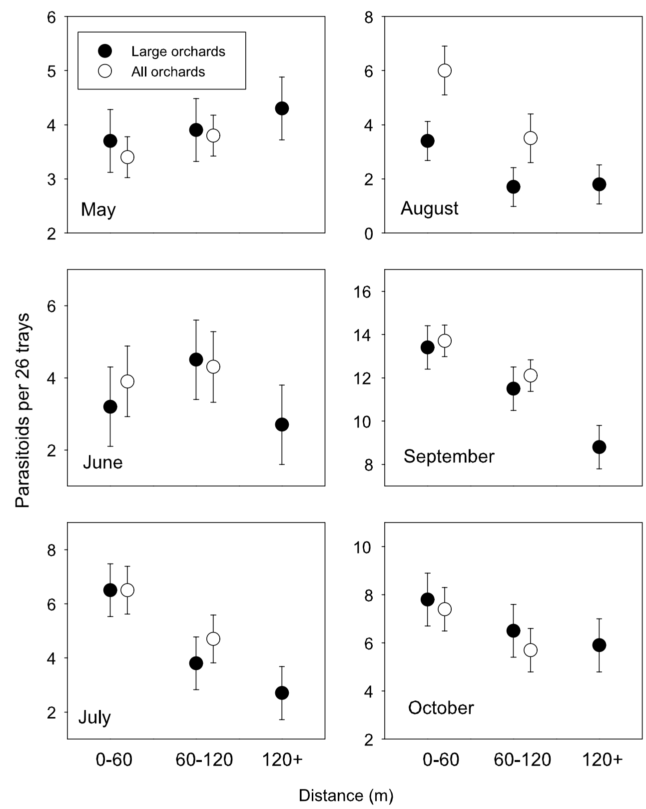

Fig. 5. Mean (± SEM) number of parasitoids per 26 trays as a function of distance into the orchard. Filled symbols: large orchards only ($N = 13$); open symbols: all orchards ($N = 18$).

orchards; Figs. 2–5, open circles). In May, July, and August, densities of beneficial arthropods declined with increasing distance into the orchard (Fig. 2, Tables 1 and 2 [overall ANOVA]), suggesting that native habitats were acting as a source from which natural enemies can move into orchards. The distance effects were due to counts of spiders and parasitoids and both groups showed a significant decline in density with increasing distance (Figs. 4 and 5; Tables 1 and 2 [overall ANOVA]). Insect predators, however, showed no such

Table 1
P-Statistics for distance effects (0–60 vs 60–120 m) from repeated measures analysis of variance using data from all 18 orchards

Month	Beneficial arthropods	Predatory insects	Spiders	Parasitoids
May	0.03	0.24	0.03	0.47
June	0.77	0.38	0.42	0.78
July	0.045	0.89	0.002	0.16
August	0.07	0.25	0.059	0.065
September	0.32	0.32	0.02	0.12
October	0.72	0.58	0.44	0.20
Seasonal[a]	0.14	0.32	0.016	0.08

Degrees of freedom = 1, 17 for each analysis.
[a] Data averaged over month before analysis.

Table 2
P-Statistics from repeated measures analysis of distance effects and profile contrasts from the ANOVA for data collected in large orchards ($n = 13$)

Month	Beneficial arthropods			Predatory insects			Spiders			Parasitoids		
	Overall	Contrasts		Overall	Contrasts		Overall	Contrasts		Overall	Contrasts	
	ANOVA	0–60 vs 60–120	60–120 vs >120	ANOVA	0–60 vs 60–120	60–120 vs >120	ANOVA	0–60 vs 60–120	60–120 vs >120	ANOVA	0–60 vs 60–120	60–120 vs >120
May	0.040	0.06	0.76	0.23			0.046	0.10	0.96	0.75		
June	0.61			0.71			0.32			0.47		
July	0.098	0.016	0.74	0.55			0.07	0.016	0.76	0.029	0.040	0.48
August	0.005	0.029	0.39	0.24			0.087	0.084	0.97	0.19		
September	0.83			0.06	0.020	0.41	0.14			0.02	0.02	0.09
October	0.99			0.34			0.42			0.45		
Season[a]	0.42			0.19			0.02	0.037	0.72	0.02	0.10	0.10

Degrees of freedom = 2, 24 for ANOVA and 1, 12 for each contrast.
[a] Data averaged over month before analysis.

pattern (Fig. 3), and there was a suggestion that predatory insects actually increased in density with increased distance into the orchards in September (Fig. 3; Table 2 [overall ANOVA]), for unknown reasons.

Seasonal means (i.e., data averaged over sample month) indicated that numbers of both spiders and parasitoids declined significantly with increasing distance into the orchard (Fig. 6; Tables 1 and 2 [overall ANOVA]).

Using data from the large orchards, profile contrasts were extracted in those repeated measures analyses that showed significant or marginally significant ($P < 0.10$) distance effects (Table 2 [contrasts]). Most of the effects were due to differences between the 0–60 and 60–120 m areas of the orchards and not to the contrast between the 60–120 and >120 m distances (Table 2 [contrasts]). This result suggests that the effects of the native habitat on natural enemy densities in the orchards were concentrated in that section of the orchard nearest the native habitat.

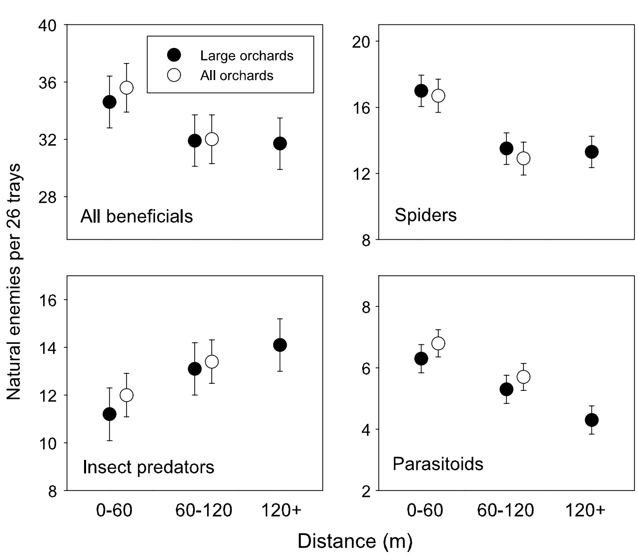

Fig. 6. Season-long average (± SEM) numbers of natural enemies per 26 trays as a function of distance into the orchard. Filled symbols: large orchards only ($N = 13$); open symbols: all orchards ($N = 18$). Data averaged over the six sample months.

3.2. Beneficial arthropods on extra-orchard host plants

Forty-five species of plants in 43 genera and 22 families that occurred in the extra-orchard habitats adjacent to study orchards were sampled for beneficial arthropods (Tables 3 and 4). Native plants included 5 tree, 15 shrub, and 13 herbaceous species while introduced plants were represented by 1 tree, 2 shrubs, and 9 herbs. Many species of beneficial arthropods collected in pear and apple orchards during this study were also collected on one or more species of extra-orchard host plant. Occurrence of these "orchard" species on extra-orchard host plants is shown in Table 3 (insects) and Table 4 (spiders). The most widespread of the insects were three true bugs (Hemiptera): *Orius tristicolor* (White), *D. brevis*, and *Nabis alternatus* Parshley occurred on 36, 21, and 21 species, respectively, of the 45 extra-orchard host plants. The spider *Misumenops lepidus* (Thorell) was found on 37 of the 45 plant species (Table 4).

Sampling effort on different host plants varied widely because of differences in the number of sites at which different species were found, variable abundance of species, ease of sampling, and whether a species was a tree, shrub, or an herb. The number of natural enemy species found on a host plant therefore reflects sampling effort as well as intrinsic factors that might make one species more attractive than another. In general, the natural enemy faunas of tree and shrub species were more diverse than those of herbaceous species, many of which remained green and succulent for relatively short periods of time, especially in sagebrush-steppe habitats (Tables 3 and 4). Twenty or more natural enemy taxa were found on five species, all of which are trees or shrubs:

Table 3
Predatory insects collected in pear and apple orchards during this study and their occurrence on native and introduced plant species in extra-orchard habitats adjacent to study orchards

Host plants	Insects																					
	Coccinella novemnotata[a]	*C. septempunctata*	*C. transversoguttata*	*Hippodamia convergens*	*H. apicalis*	*Harmonia axyridis*	*Cycloneda polita*	*Mulsantina picta*	*Stethorus picipes*	*Deraeocoris brevis*	*Campylomma verbasci*	*Orius tristicolor*	*Anthocoris* spp.[b]	*Geocoris* spp.[c]	*Nabis alternatus*	*Brochymena* sp.	*Chrysoperla rufilabris*[d]	*C. plorabunda*	*Chrysopa oculata*	*C. nigricornis*	*C. coloradensis*	*Hemerobius* spp.[e]
A. tridentata			X		X			X		X	X	X		X	X			X	X	X	X	X
C. nauseosus			X		X					X		X	X	X	X		X				X	
Chrysothamnus viscidiflorus		X												X								
Solidago canadensis												X							X			
A. millefolium											X	X			X							
Balsamorhiza sagitatta				X								X			X							X
Machaeranthera canescens												X		X								
Helianthus cusickii																						
*C. arvense**		X	X							X		X		X	X			X			X	
*Centaurea solstitialis**												X		X								
Centaurea sp.*												X		X	X							
P. tridentata				X		X			X	X	X	X	X	X	X						X	
P. virginiana												X				X						
Holodiscus discolor										X	X	X		X			X					
Aruncus sylvester										X							X					
Rosa sp.								X		X		X										
*Rubus discolor**										X		X					X			X		
Atriplex spinosa	X																					
*Salsola iberica**			X									X	X	X	X							
Cl. ligusticifolia					X					X		X			X							
Berberis aquifolium										X												X
S. albus									X	X		X						X				
Sambucus cerulea												X						X				
P. ponderosa		X						X		X		X						X				X
P. menziesii								X	X	X		X										X
Apocynum androsaemifolium																						
S. exigua									X	X	X	X	X		X	X					X	
P. trichocarpa						X	X		X	X		X	X			X		X			X	X
*Populus nigra**						X				X		X	X									
Epilobium angustifolium												X										
Eriogonum elatum										X		X										
*Rumex crispus**		X		X						X		X		X								
*Hypericum perforatum**												X										
*Sisymbrium altissimum**											X	X										
Asclepias speciosa											X	X										
*Verbascum thapsus**			X								X	X		X	X				X			
Lupinus spp.		X										X		X	X				X			
*Cytisus scoparius**										X		X			X					X	X	X
*Melilotus officinalis**												X										
A. macrophyllum									X								X					X
Q. garryana		X					X		X	X			X				X	X		X	X	X
C. integerrimus										X		X			X		X	X		X	X	
R. aureum													X									
Lomatium grayi												X		X								
A. occidentalis											X	X										

Introduced plant species marked with an asterisk (*).
[a] Coccinellid records, except *S. picipes*, are for identified adults only. Larvae were not identified to species and larval data are not included in the table.
[b] *Anthocoris whitei* and *A. antevolens*.
[c] *Geocoris pallens*, *G. bullatus*, and *G. atricolor*.
[d] Records of Chrysopidae include adults and larvae.
[e] Records of *Hemerobius* spp. include identified adults (species given in text) and unidentified larvae.

Table 4
Spiders collected in pear and apple orchards during this study and their occurrence on native and introduced plant species in extra-orchard habitats adjacent to study orchards

Host plants	Spiders																					
	Phidippus spp.[a]	*Pelegrina aeneola*	*Sassacus papenhoei*	*Metaphidippus vitis*	*M. mannii*	*Salticus scenicus*	*Oxyopes scalaris*	*Xysticus cunctator*	*Misumenops lepidus*	*Philodromus rufus*	*P. cespitum*	*P. insperatus*	*P. dispar*	*P. spectabilis*	*Tibellus oblongus*	*Cheiracanthium mildei*	*Anyphaena pacifica*	*Meioneta fillmorana*	*Erigone dentosa*	*Spirembolus mundus*	*Theridion neomexicanum*	*Tetragnatha* spp.[b]
A. tridentata	X		X				X	X	X						X		X	X			X	X
C. nauseosus	X		X				X		X						X		X	X	X		X	
C. viscidiflorus	X		X	X			X	X	X						X		X		X			X
S. canadensis	X		X	X				X	X			X					X		X			
A. millefolium			X						X											X		
B. sagitatta	X		X				X	X	X									X		X		
M. canescens	X		X						X													
H. cusickii	X						X		X								X					
*C. arvense**	X	X	X				X		X		X	X			X		X	X				X
*C. solstitialis**	X						X		X						X							
Centaurea sp.*			X				X		X				X		X						X	
P. tridentata	X		X			X	X	X	X			X				X	X	X	X		X	X
P. virginiana				X	X				X													
H. discolor	X						X		X								X	X		X	X	
A. sylvester		X					X		X	X			X					X				
Rosa sp.	X		X	X			X		X				X		X		X	X	X	X	X	
*R. discolor**	X				X		X		X				X		X			X		X		
A. spinosa	X							X											X			
*S. iberica**	X		X				X		X						X							
Cl. ligusticifolia	X	X	X	X			X		X			X			X		X		X			X
B. aquifolium	X			X	X		X						X		X	X					X	
S. albus	X	X			X		X		X				X		X	X	X	X		X	X	
S. cerulea				X			X		X												X	
P. ponderosa	X						X			X			X	X				X			X	
P. menziesii	X	X					X			X			X					X	X	X	X	
A. androsaemifolium									X													
S. exigua	X	X	X	X		X	X	X	X		X	X			X	X	X		X			X
P. trichocarpa	X			X		X	X	X	X							X	X		X			X
*P. nigra**		X																		X		X
E. angustifolium									X													
E. elatum	X		X				X	X	X													X
*R. crispus**	X		X				X	X									X					
*H. perforatum**							X										X	X				
*S. altissimum**		X						X	X									X				
A. speciosa	X		X					X	X			X			X			X				
*V. thapsus**	X		X					X	X									X	X			
Lupinus spp.		X	X						X													
*C. scoparius**		X					X		X				X					X		X		
*M. officinalis**									X													
A. macrophyllum									X	X							X	X		X	X	
Q. garryana							X		X	X			X			X	X	X		X	X	
C. integerrimus	X	X			X	X	X		X	X		X	X	X	X	X	X	X		X	X	
R. aureum	X														X		X					
L.. grayi			X					X	X													
A. occidentalis	X							X	X													

Introduced plant species marked with an asterisk (*).

[a] Four species represented (*P. audax*, *P. clarus*, *P. johnsoni*, and *P. comatus*), early instars of which are not distinguishable. All four species were also taken in orchard collections.

[b] *T. laboriosa* and *T. versicolor*, both of which were taken in orchards.

A. tridentata Nutt., *P. tridentata* (Pursh), *Salix exigua* Nutt., *P. trichocarpa* T. & G., and *Ceanothus integerrimus* H. & A. Among herbaceous species, the perennial herb *Cirsium arvense* (L.) Scop. and the perennial vine *Clematis ligusticifolia* Nutt. hosted 19 and 15 natural enemy species, respectively. Both had long flowering periods and remained green through much of the season at their respective sampling sites. Other herbaceous plants hosted fewer species of natural enemies but they were abundant during flowering, probably due to abundant prey. *Achillea millefolium* L. and *Agastache occidentalis* (Piper) Heller were two examples.

4. Discussion

Habitats adjacent to pome or stone fruit orchards may be sources of pest arthropods that can move into the orchards (Jeanneret, 2000; Kaloostian, 1970; Pearsall and Myers, 2001; Thistlewood et al., 1990). Extra-orchard habitats adjacent to orchards also appear to be sources of natural enemies that may enter orchards and subsequently attack arthropod pests (Herard, 1986; Horton and Lewis, 2000; Nguyen and Merzoug, 1994; Nguyen et al., 1984; Rathman and Brunner, 1988; Scutereanu et al., 1999). For instance, certain tree and shrub species, particularly in the Salicaceae and Rosaceae, support non-pest psyllids which are attacked by true bug predators and parasitoids (Horton and Lewis, 2000; Nguyen and Merzoug, 1994; Nguyen et al., 1984). Several of these natural enemy species are also important sources of mortality for pest psyllids in apple and pear orchards (Horton and Lewis, 2000; Nguyen et al., 1984; Solomon, 1982; Solomon et al., 1989).

Much of the evidence that extra-orchard habitats act as sources of natural enemies in orchards is correlative, being based on observations that orchards and neighboring, extra-orchard habitats often share predatory and parasitic taxa (Horton and Lewis, 2000; Nguyen et al., 1984; Rathman and Brunner, 1988). More direct assessments of the importance of non-orchard habitats as sources of biological control agents are few. Rathman and Brunner (1988) monitored arthropod colonization of potted apple trees that had been placed in riparian or sagebrush steppe habitats. They concluded that colonization rates varied with time of year, habitat, and arthropod taxon and that riparian habitats were better sources of natural enemies than sagebrush steppe habitats. In a similar vein, Gut et al. (1988) monitored arthropod colonization of young pear trees that had been placed in different agricultural settings (a mixed crop assemblage versus a pear monoculture) rather than native habitats. Differences were noted in arthropod species richness on the young pears and also in the kinds, abundances, and arrival times of arthropods on the pears depending on the surrounding habitat.

In this study, we indirectly looked at whether natural enemies colonize apple and pear orchards from extra-orchard habitats by comparing densities of beneficial arthropods in the orchards at several distances from the extra-orchard habitats. Total beneficial arthropods, spiders, and insect parasitoids exhibited significantly higher densities in portions of the orchards near the extra-orchard habitats (Tables 1 and 2; Figs. 2, 4, and 5), results consistent with our hypothesis that extra-orchard habitats act as sources of beneficial arthropods that move into orchards. Densities of predatory insects were not affected by distance (Tables 1 and 2; Fig. 3), suggesting that they were not colonizing the orchards in large numbers from neighboring habitats, or that their dispersal rates were high enough that distance effects were obscured. The largest effects for taxa that showed a decline with distance trend appear to have occurred in May and in mid-summer (Tables 1 and 2; Figs. 2, 4, and 5), suggesting that colonization of orchards from neighboring, extra-orchard habitats was highest at these times. Neither the May nor the mid-summer decline with distance trends could be attributed to a single species, and different species contributed to the trend in different orchards. Also, magnitude of the effect varied among the orchards. The summer influx of spiders could have been related, in part, to deterioration of non-orchard habitats as vegetation began to dry, especially in the sagebrush steppe habitats common in the study area.

Beneficial arthropods collected during this study could roughly be divided into three groups. One group consisted of species found within orchards but rarely taken in certain extra-orchard habitats. An example was the jumping spider *P. aeneola*, a species that can be a dominant component of the spider fauna of organic orchards in the Pacific Northwest (Horton et al., 2001; Miliczky et al., 2000). *P. aeneola* however, was rarely taken on plants typical of the sagebrush steppe habitat found adjacent to many of our study orchards. On the other hand, it was found on species associated with mixed oak/conifer woodland and on species that grew under the moister conditions along orchard borders and irrigation canals, including *P. menziesii*, *C. arvense*, and *S. exigua* (Table 4). *P. aeneola* (as *Metaphidippus aeneolus*) is a common species in mixed coniferous forests throughout the pacific northwestern United States (Mason and Paul, 1988; Moldenke et al., 1987). *C. mildei*, a spider often found in Pacific Northwest orchards (Horton et al., 2001; Miliczky et al., 2000), was also rarely taken on sagebrush steppe associated plants but it did occur on species typical of more mesic environments (Table 4). Important parasitoids of orchard pests such as *T. insidiosus* and *P. flavipes*, which have restricted host ranges, were not collected on any of the extra-orchard host plants that we sampled.

Beneficial arthropods that occurred in certain extra-orchard habitats but were of rare occurrence in adjacent orchards comprised the second group. Spiders included *Pelegrina helenae* (Banks), *P. clemata* (Levi & Levi) and *Philodromus histrio* (Latreille) while predatory insects included unidentified species in the Reduviidae, Phymatidae and Raphidiidae. All were collected, and were at times common, on sagebrush steppe plants such as *A. tridentata* Nutt., *P. tridentata* (Pursh), and *Chrysothamnus nauseosus* (Pall.) Britt. We assume that these predators have prey, habitat or microenvironment requirements that are not met within adjacent orchards.

The third group of beneficial arthropods, and the one of greatest interest with regard to this study, includes species found both in the orchards and on various extra-orchard host plants (Tables 3 and 4). Many insects in Table 3 contribute to biological control of orchard pests and include predatory Heteroptera, Coccinellidae, and Neuroptera (Beers et al., 1993; Madsen et al., 1963; Nickel et al., 1965; Westigard et al., 1968). Species of *Anthocoris*, for example, were most commonly found on plants such as *P. tridentata*, *S. exigua* Nutt., and *Ribes aureum* Pursh that are hosts for psyllids (see also Horton and Lewis, 2000; Horton et al., 2004). Extra-orchard plants appeared to be most attractive to some predators during flowering. *C. nauseosus* (Pall.) Britt., for example, was populated by large numbers of *O. tristicolor* while in flower, presumably due to the abundant western flower thrips, *Frankliniella occidentalis* (Pergande), that occurred in the blossoms.

The role of spiders in orchard biological control has received less attention than the role of insect predators and parasitoids. Several spiders in Table 4 are numerically important components of the predator fauna in Pacific Northwest orchards, including *P. aeneola*, *O. scalaris*, *P. cespitum*, and *M. fillmorana* (Horton et al., 2001; Miliczky et al., 2000). Some species in Table 4 are potentially important predators of pest leafrollers in orchards (Miliczky and Calkins, 2002). As with some of the predatory insects, certain spiders were particularly abundant on extra-orchard plant species during flowering. The crab spider *M. lepidus*, for example, was common on flowering *C. nauseosus*, apparently due to the availability of prey such as thrips or flower-visiting Diptera and Hymenoptera.

Apple and pear producers in the United States' Pacific Northwest are relying more heavily on natural enemies for control of orchard pest arthropods for reasons that include loss of insecticides and greater restrictions on their use, public safety concerns including farmworker exposure to insecticides and their residues, and development of insecticide resistance among some pest species. As this trend seems certain to continue, improved understanding of the biology and ecology of natural enemies will be a prerequisite for taking full advantage of their potential contributions to pest control. Greater knowledge of natural enemy relationships with extra-orchard habitats is one area that seems likely to benefit pest control by natural enemies. This research has shown that many natural enemy species found in orchards also utilize plants outside of the orchard and likely move between the two habitats. Habitats outside of the orchard are not generally subject to chemical and cultural control measures that can be detrimental to natural enemies and may thus provide refugia for these organisms. Preservation or modest efforts to improve or enhance extra-orchard habitats and their associated plants may thus benefit natural enemies and, in turn, pest control in adjacent orchards.

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